A PSA Framework for Interim Storage Facility Subject to Aircraft Engine Crash

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1. Introduction

A new PSA (Probabilistic Safety Assessment) framework is developed for an interim storage facility of spent nuclear fuel considering a targeted aircraft crash. It includes key elements of PSA such as event tree analysis, radiological consequence analysis together with a sophisticated structural analyses for the storage building, metal cask and spent fuel assemblies to calculate the release fraction of radionuclides due to an impact of aircraft engine into the facility. The developed framework is applied to a reference storage facility which consists of a reinforced concrete (RC) building and a single cask containing 24 PWR fuel assemblies. Three levels of structural resilience are considered together with 3 burn-up rate of fuels. It was shown that the strike of an aircraft crash does not pose a significant risk to the public in all 3 levels of structural resilience.

2. Methodology Overview

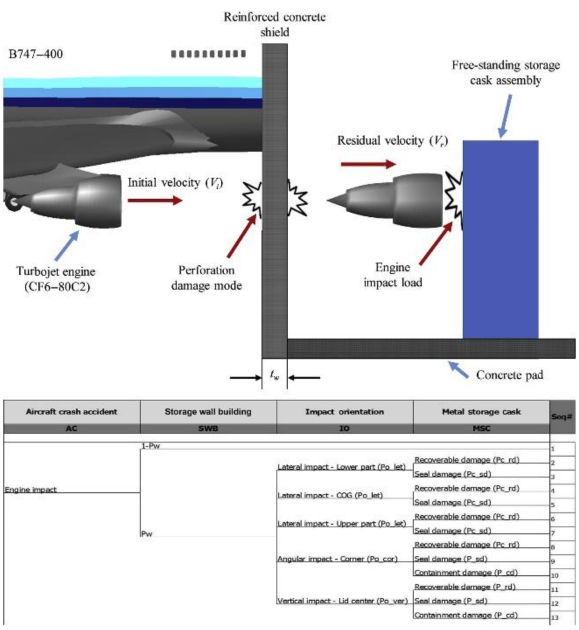

Fig. 1. Aircraft crash scenario and event tree.

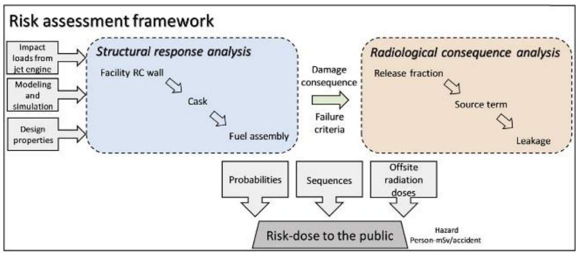

Fig. 2. Risk assessment framework.

The impact scenario and the risk assessment framework is illustrated in Fig. 1 and 2. A targeted aircraft crash is considered and its radiological consequence is calculated with inputs from a sophisticated structural analyses on the facility [2].

3. Structural Analyses

3.1 Storage building local damage analysis

As a best deterministic estimation, with a bias toward conservatism, as suggested in the NEI report [1], the empirical formulas employed in this study can predict the minimum RC wall thickness required to prevent local damage caused by the normal impact of an aircraft engine and its residual velocity. Impact speeds and compressive strengths of concrete are treated probabilistically as uncertainty.

3.2 Cask response analysis

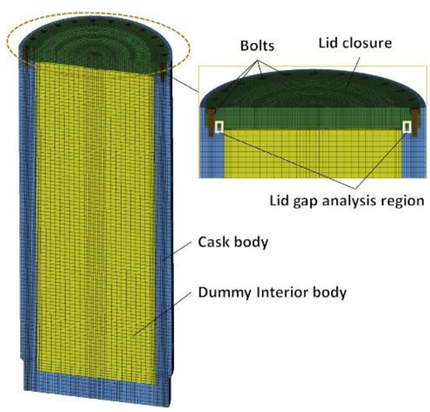

Fig. 3. Cask analysis model to calculate leak path area.

A detailed finite element model (Fig. 3) was developed to analyze the dynamic response of the lid closure system in order to calculate the leakage path area between the lid and the flange, since the lid seal plays an essential role in preventing the escape of fine particulates and radioactive gases from the cask. It is assumed that a closure opening greater than the pre-compression state of the metallic seal will cause leakage. Various velocities and impact locations were considered as sources of uncertainty.

3.3 Fuel assembly analysis

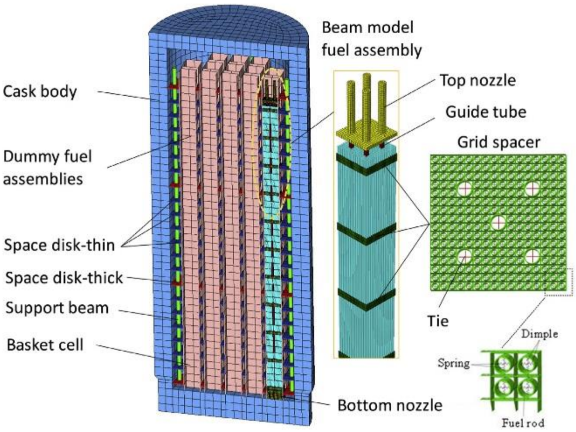

Fig. 4. Detailed fuel assembly analysis model.

Another cask model with detailed fuel assembly was developed to analyze the dynamic response of the fuel assembly and estimate the fraction of rods that fail during the impact as an essential parameter of the radiological consequences. The impact analysis studied five impact orientations. The effect of impact angle is also studied together with the impact location and the jet engine of a B747 was chosen for this study to provide an upper bound impact load on the cask body. One assembly in the proximity of impact location is modeled with full details while the other 20 assemblies are modeled as dummy weights.

4. Radiological Consequence Analysis

Three inventories for the radionuclides involved in the scenario that dominate the inhalation dose for all the chemical elements classes (volatiles, fission gases, and solid particles) are calculated using the ORIGEN-ARP of SCALE v.6.1.3 code. The computer code HOTSPOT v.3.0.2 which was developed based on the Gaussian dispersion plume model, is used in this study to estimate the radionuclide spread from the accident. The reference person is presumed to have a breathing height of 1.5 m and a breathing rate of 3.47Ee4 m^3/s. The wind speed reference height is 80 m and the release height is ground level.

5. Risk Estimation

The dose-risk elements are the product of the probabilities of the impact condition and the corresponding responses (Pw, Po, and Pc), and the fractions that lead to the release of radioactive materials that cause radiological consequences of magnitude (C). The measure of risk is given by Eq. (1), which is applied in sequence line i:

$$R_i = P_w P_o P_c \times C_i \tag{1}$$

The initiating frequency of the aircraft crash accident is assumed to be 1, representing an intentional aircraft crash. As the storage wall building is the first barrier to protect the internal spent fuel storage casks from the AI, the results of the probability of perforation (Pw) for facility walls (low, median, and high) are inserted accordingly into Column 2 of event tree. Then, the probability of each impact orientation is added in Column 3. Finally, the probability results of the cask response status for the three structural performance levels of metallic seal, are inserted into Column 4. All probability data are multiplied. The maximum possible radiological consequences for each sequence line, are inserted into the Consequence column for the three rates of fuel burnup. Finally, through Eq. (1), the expected hazard to the public can be estimated in units of mSv/accident. In all cases, the risk was calculated below the design basis accident limits.

6. Conclusions

A new PSA framework for aircraft crash into an interim storage facility has been developed and applied to a reference facility. Fire accident and secondary impact of cask with other structure will be covered in future research.

REFERENCES

[1] Nuclear Energy Institute, Methodology for performing aircraft impact assessment for new plant designs, Revision 8P (2011).

[2] Almomani, B., Lee, S., Jang, D., Kang, H.G., "Probabilistic risk assessment of aircraft impact on a spent nuclear fuel dry storage," Nuclear Engineering and Design. 311. 104-119 (2017).